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Evaluation of the Effectiveness of Hands-On Corrosion Control Training Using Metered Resistance Measurements to Assess Sailors' Comprehension

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EVALUATION OF THE EFFECTIVENESS OF HANDS-ON CORROSION CONTROL TRAINING USING METERED RESISTANCE MEASUREMENTS TO ASSESS SAILORS' COMPREHENSION

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CHAPTER I

INTRODUCTION

Corrosion is the unplanned eroding of material due to chemical reactions, normally oxidation. When gases or liquids come in contact with metal surfaces and are accelerated by heat, acids, or salts, corrosion will occur. As the process continues a patina of carbonates or oxides will form on the surface. On a ship, the patina is better recognized as rust. Corrosion comes in the form of galvanic reaction, rusting, pitting, mineral buildups, degradation due to ultraviolet light exposure, mold, mildew, or other organic decay responsible for the costly destruction and deterioration of military systems and infrastructure (GAO, 2004).

Navy ships are metal structures floating in salt water and are constantly exposed to changing temperatures, wind, and salt air. This kind of harsh environment is very favorable to corrosion and ends up being very costly to repair. In 2001, a government-sponsored study estimated that corrosion was the number one life-cycle expense for the military, costing approximately $20 billion dollars annually. Additionally, corrosion negatively affects combat readiness, is a safety issue, and causes poor morale (Koch et al., 2001).

A ship's topside is comprised of numerous metal objects of varying sizes. These items may be large structures like cranes, masts, and davits, or they may be much smaller like bolts, antennas, and climber safety devices. All of these items are susceptible to corrosion and will require some kind of corrosion preventive or corrective maintenance.

A main part of a ship's topside are the different weapon and antenna systems, cable runs, and associated fixtures which make up combat systems. These systems are mounted using many different methods, requiring a wide variety of corrosion control methods.

Since a ship may be at sea for a long time, it only makes sense that the crew should have the knowledge and ability to fix corrosion problems within their scope and be able to perform a self-assessment on the success of their work. A deployed unit is very expensive and time consuming to support. Armed with the right kind of tools and knowledge, survivability will increase, costs will drop, and the crew's morale will improve.

STATEMENT OF PROBLEM

The problem of this study was to evaluate the success of combat systems topside preservation training using a cost effective method to self-assess the efficiency of shipboard corrosion control procedures.

HYPOTHESIS

The following hypothesis was developed to guide this study:

H_1: On Navy ships calibrated ohm measurements will better quantify the effectiveness of present shipboard topside corrosion control practices.

BACKGROUND AND SIGNIFICANCE

Corrosion is a problem costing the military billions of dollars. A quarter of the Atlantic and Pacific Fleets' budget go toward the prevention and correction of corrosion (GAO, 2004). Corrosion has impacted the operational readiness of many ships. The vessels operate in highly corrosive salt water and high humidity areas. As an example of the problem, in 2001, corrosion related problems onboard the USS John F. Kennedy were so bad that the aircraft carrier could not deploy. Corrosion related problems are found throughout the Navy. On a regular basis ships are scheduled for yard periods where much of the work is dedicated to correcting corrosion related problems. During this yard period, a ship may be out of action for up to and beyond six months (GAO, 2004).

Safety is also affected by corrosion. Landing gear and avionics on aircraft have fallen victim to corrosion, resulting in crashes. Mounting hardware for ladders, climber-safety rails, and antennas have the potential of decaying to the point where they may cause injury.

A process of proactively instructing the combat systems sailor in different methods of topside preservation and corrosion related maintenance will greatly improve the operability of the ship. Equipment will remain online longer and corrosion related problems will be repaired correctly. Maintaining the systems properly will allow the ship to more readily meet its commitments and reduce delays in meeting operational commitments. When a ship cannot deploy on time, high costs are encountered preparing another ship to take its place.

System survivability will improve as the equipment is better maintained. The sailors will gain a better understanding of corrosion and the need to combat it promptly and correctly. They will learn that properly employed preventive methods will reduce the reappearance of corrosion. The sailors will also learn that if corrosion returns, correctly executed preventive measures will make corrective actions easier in the future. The simple act of applying the proper anti-seize to a bolt's threads and appropriately weather-sealing its head will make bolt removal relatively easy for years to come. Armed with a better knowledge of corrosion a sailor's interest in the science may peak and they may wish to pursue further education in the corrosion field. The sailors will learn while doing. While they are being lectured, these shipboard technicians will be able to closely visualize the problems, take a resistance check if possible, identify the type of corrosion and learn to apply the proper corrective and preventive measures. By self-checking their work and observing a correct resistance reading on an ohm meter a sailor will experience an immediate boost in confidence and this success will render a sense of accomplishment.

The money lost to corrosion is a great deal. Having a more knowledgeable and better trained sailor will cut costs. They will have a better understanding of the corrosion process; they will be able to better recognize the problem; and they will know the proper procedure to correct the problem. Once the sailor has a resistance record of different topside test points, they will be able to use resistance checks as a history. If corrosion is suspected of reappearing in the same location, they will be able to use the resistance check as a first measure of corrosion. This procedure will also prove to the sailors that their work was successful and give them a sense of ownership.

LIMITATIONS

The limitations of this study were identified as follow:

1. The study was based on two U. S. Naval ships of the same class.
2. Each ship had different corrosion problems which limited the kind of training given on each platform.
3. Weather and time aloft limited the location and amount of time that could be dedicated to the kind of training.
4. Cost limitations did not permit using radiating elements to provide more in depth results.
5. The data gathered were not precise. Sampling data from ship to ship was different since their corrosion problems were not identical. Since resistance of corrosion is affected by humidity, moisture in cracks and crevices and between metal-to-metal joints, was not always completely vacated of moisture.
6. Access to locations on a ship was not available. Ships were replacing warn deck coatings and non-skid surfaces. This process lasted two weeks, restricting access to different parts of the ship.
7. The ships also held many drills which, occasionally, limited movement and took sailors away from training.
8. The amount of anti-seize applied between metal surfaces was not uniform, affecting impedance measurements over a period of time.
9. The sealant used was not given ample time to dry before applying primer and paint and may peel away exposing repaired surface.

10. The paint used was not applied at the optimum temperature and may not last as long as it would if applied at the proper temperature.
11. The Corrosion Resistant Steel (CRES) replacement hardware may not have been manufactured properly resulting in poor corrosion resistant properties.
12. Treatable corrosion products were limited oxides created from steel, aluminum, and copper.
13. The list of problems presented by the combat systems officer or electronic material officer may not have included all corrosion problems.

ASSUMPTIONS

The following assumptions were made regarding this study concerning the effects of remediation programs:

1. All sailors being trained will be technicians working in the electronics background.
2. All topside work will be done on dry days.
3. During the training all of the ship's safety procedures will be followed.
4. Those technicians undergoing training will have experience troubleshooting.
5. The training is not part of a sailor's non-judicial punishment and the technicians are willing participants.

PROCEDURES

The subjects of this study were Navy technicians stationed on board two different ships. Before visiting the ship, the combat systems officer and electronic material officer will compile a list of problems caused by corrosion. After the problems have been identified, the correct material and processes will be identified and brought to the ship.

Just prior to performing a process, an impedance measurement will be taken using an ohm meter and documented. Under the instruction and supervision of an instructor, the process will be completed. During the training the sailors will have learned some of the science behind corrosion, its cause and affects, and gained a better understanding for the need for corrosion prevention. After the process has been completed, another impedance measurement will be taken and balanced against the previous measurement. These measurements will be used to evaluate the effectiveness of the corrosion control procedure. Each corrective procedure may be different, but the self-assessment will be the same. Each sailor was asked to complete a questionnaire that inquired about the value of the training and the usefulness of the information. Additionally, they were asked if taking resistance measurements helped in their understanding of corrosion control efforts.

DEFINITION OF TERMS

The following definitions are defined to aid the reader:

1. Chemical energy – In a molecule it is the energy held in covalent bonds and atoms.
2. Climber-Safety-Rail (CSR) – A rail mounted behind or beside a ship’s ladder where a sailor attached a climber safety device and harness in order to climb a mast.
3. Combat Systems – A department on-board ship dedicated to maintaining the ship’s combat related systems.

4. Corrosive Resistant Steel (CRES) – Stainless steel that is not susceptible to corrosion.
5. Ohm Meter – A meter used to measure ohms.
6. Surroundings – An imaginary boundary wall surrounding a system, separating it from the environment.
7. Systems – Any particular mass or material of interest.
8. Thermodynamics – The study of energy changes employing variable quantities, equations, and many definitions.

OVERVIEW OF CHAPTERS

Chapter I of this research study provided an introduction into corrosion and some of the historical and negative effects it has had on military systems. The chapter covers the high cost of maintenance, operation time lost, and many hours used addressing corrosion related problems. As part of the Navy's fight against corrosion, a more hands-on approach to training sailors in corrosion control methods has been introduced to several of the ships. Students assigned to combat systems will be taught to take a base-line resistance measurement, perform the required procedure for whatever system they may be working on at the time, and take another measurement upon completion. With this information, the sailor and the ship can evaluate the success of their efforts and use the information later as a reference.

Chapter II examines the literature that is related to this research covering a basic understanding of the science of corrosion; some of the causes and effects of corrosion and procedures relating to historical corrosion control methods employed on ships is provided. The science provides knowledge necessary for understanding the degrading effects. The cause and effect data overviews the corrosion process and gives an idea of what needs to be done to correct the problem. The historical review looks at some of the past approaches and appraises some being more successful than others.

Chapter III addresses the methods and procedures used in this research on training sailors to execute specific corrosion control and perform self-assessments. The procedures include recognizing the problem, partnering it to the correct procedure, and taking preliminary measurements. The procedure will then begin. Once the procedures are completed, the subsequent step is to measure once again. Comparing these two measurements, an evaluation of success can be determined.

Chapter IV provides findings relating to the research. Sailors were asked to complete questionnaires upon completion of training. Tables cover results of returned questionnaires.

Chapter V summarizes the data collected and presents conclusions and recommendations resulting from the study. Conclusions will be drawn from the task performance, the opinions of success provided by the students, and the before and after resistance measurements taken.

CHAPTER II

REVIEW OF LITERATURE

This chapter provides a review of literature related to topics on the high cost of corrosion, the Navy's approach, a basic understanding of corrosion, the Navy's need for hands-on corrosion control training, wave propagation effects on shipboard structures, antennas and related systems operation, the structure of remediation, and present and future assessments. The covered variables have been significant for remediation programs in the past, are important in the present, and will continue to be crucial in the future.

THE HIGH COST OF CORROSION

In 1998, the Congress of the United States passed the Transportation Equity Act for the 21st Century (TEA-21), which included an amendment with the expressed purpose of assessing corrosion costs throughout the country. Beginning in 1999, the Federal Highway Administration (FHWA) organized an interdisciplinary group of metallurgists, chemists, economists, and other professionals. The mission of this specialized team was to perform a government sponsored corrosion cost study by evaluating the total cost of metallic corrosion to the country and, upon completion, offer possible precautionary measures designed to mitigate the impact of corrosion. At the end of the study in 2001, the team estimated that the direct cost of corrosion accounted for $276 billion dollars annually, or 3.1% of the gross domestic product of the United States (Cramer & Covino 2003). The direct cost was defined as, "the cost incurred by owners or operators of the structure, manufacturers of products, and suppliers of services" (FHWA, 2001, p. 2).

In addition to assessing direct cost, attempts were made to put a value on the indirect cost. The group defined indirect cost as, "(1) lost productivity because of outages, delays, failures, and litigation, (2) taxes and overhead on the cost of the corrosion portion of goods and services, and (3) indirect costs of non-owner/operator activities" (FHWA, 2001, p. 13). Since numbers and values were either very difficult to obtain or not available, the team conservatively assumed the value of indirect cost to be the same as direct cost.

The FHWA (2001) study found that the direct cost to the Department of Defense (DOD) amounted to approximately $20 billion. According to the United States General Accounting Office (GAO) (2003), the personnel and material needed for corrosion inspection and maintenance were identified as direct cost and agreed with the FHWA (2001) approximation of $20 billion. Indirect costs were trickier to appraise. Defined as, "the loss of the opportunity to use equipment that is not in operating condition" (GAO, 2003, p. 7), and having an enormous inventory of assets, the financial impact of downtime was not accurately measured.

A more complicated task was putting a price-tag on the equipment operated in a weaken state due to corrosion. Corrosion shortens the lifespan of equipment and hastens the depreciation of military facilities. The total value of military equipment devastated by corrosion is huge and the GAO (2003) report estimates replacement value of over $435 billion. "This impact on facilities translates into costs that are not included in the government corrosion cost study" (GAO, 2003, p. 7).

The U. S. Navy is especially concerned about corrosion. Its ships operate in an environment of highly corrosive salt water, changing temperatures, and high humidity. The Navy estimates that 25 percent of its budget is dedicated to corrosion control and prevention. Even though many of the major corrosion problems are addressed during 6 month yard periods, on a ship, the battle with corrosion is a daily event and often labor intensive. The Navy is consumed by corrosion inspections and the time used for corrosion related maintenance could be better used on training for combat readiness GAO (2003).

THE NAVY AND THE BIG PICTURE

According to the GAO (2003), the Navy does not have a solid corrosion control strategy and its corrosion control offices do not have the information or metrics necessary to track progress. Attempts were made to, “establish a corrosion control and prevention program, but the plan – which included goals and objectives and outlined how progress would be measured – was never approved” (GAO, 2003, p. 7). Even though many of the procedures were standard, there was no effective way to evaluate their performance.

According to the 2001 report by FHWA, in order to combat corrosion a preventive strategy includes: (1) an increase in the awareness of significant corrosion costs and potential cost-savings, (2) change the notion that nothing can be done about corrosion, (3) policies, regulations, standards, and management practices need to be changed to increase cost-savings, (4) training and education of staff in the area of corrosion recognition has to improve, (5) better design practices need to be adopted, (6) advanced life predictions and performance assessment methods need to be developed, and (7) by using research, development and implementation, corrosion technology needs improvement.

Embracing this idea the Navy has developed a team of corrosion engineers, technicians, and other experts tasked with going on board ships and providing hands-on training to the sailors in different areas of corrosion control. The team will visit a ship for a predetermined amount of time and provide awareness training of procedures, both old and new. Innovative protective coatings and measures will be introduced and their effectiveness will be evaluated. A matrix will be maintained on a daily basis with the purpose of reviewing procedures, addressing questions, and evaluating progress. The ship's entire chain of command is kept in the information loop and feedback is freely exchanged. After the initial visit is complete, the matrix is then used as a history of what has been done. Future visits will be scheduled, and using the matrix as a historical document, the team can return and assess the success of the products and procedures. Depending on the success or failure of the product or procedure it will be either adopted or a new method will be introduced.

Training and education in the U. S. Navy is extremely important and it is considered an asymmetrical advantage. Teamwork, collaboration, communication, coordination, and knowledge are vital to their success. The Naval Education and Training Command [NETC] is dedicated to creating a Navy using an education program directed at honing a sailor's personal and professional skills (NETC, 2010).

COMBAT SYSTEMS AND CORROSION

Corrosion is a natural process and has been a problem for a long time. For most people, corrosion is recognized as rust. Rust is not the actual corrosion, but a product of corrosion of iron (Tretheway & Chamberlain, 1988). According to Schweitzer (2007) corrosion is the degrading of a material's mass or properties over a period of time and the patina or visible rust is oxidation. Recognizing corrosion is not a new concept, "The great Roman philosopher, Pliny, AD23-79, wrote at length about ferrum corrumpitur, or spoiled iron" (Trethewey and Chamberlain, 1988, p. 4). Identifying corrosion and attempts to rid material of corrosion has been an ongoing struggle.

Witnessing any metal structure or ship exposed to the harsh ocean environment over a period of time, one would observe obvious signs of corrosion. The most apparent would be rust. This oxidation may be observed running down the side of the ship in the form of deteriorating bolts, stanchions, or ladders, or may show up at the bases of antennas. Wherever rust appears, it is a product of corrosion and indicates the deterioration has already begun (Trethewey & Chamberlain, 1988).

Since the Combat Systems Department on a U. S. Navy ship is comprised of antennas, antenna platforms, and other mating surfaces, corrosion is not always evident. "Shipboard antenna mounts are subject to severe weather conditions because of their location. Their relative inaccessibility sometimes results in their being neglected by maintenance crews" (Cady, Karelitz, & Turner, 2008, p. 12). It is imperative that all metal-to-metal mating surfaces located on a ship's topside be corrosion free. Whether the corrosion is part of the antenna system or not, its presence may alter the desired radiation patterns (Kraus, 1988). Corrosion can enter between mounting surfaces for ladders, stanchions, external lights, handrails, climber-safety rails, and davits – and any of these items may be located within the radiation pattern of an antenna. Corrosion on these surfaces may cause inter-modulation which is the unwanted mixing of two or more frequencies in non-linear junctions, re-radiating product orders, and reducing operation capabilities of other systems (Rembovsky & Ashikhmin, 2009).

Once corrosion has taken hold, the impedance of the mating surface will vary depending on the saltwater allowed to intrude (Ohtsuka, Komatsu, & Sasaki, 2007). When this happens between the base of an antenna and its mounting surface, the antenna system may experience an impedance mismatch (Stutzman & Thiele, 1981), and since this state is affected by water, the faulty indications may be intermittent and very difficult to detect.

CORROSION A BASIC UNDERSTANDING

In 1761, the British Navy covered the hull of one of its frigates, the HMS Alarm, with thin copper to reduce damage brought on by the toredo woodworm and, it was hoped, that the toxicity of the copper would reduce barnacle growth. After deploying for two years, the ship was run-aground in order to evaluate the effects of the experiment. It was found that the sheathing had detached from the hull and the iron nails used to hold the copper in place had corroded. Closer inspection revealed that some of the nails had not corroded as much as others. The brown wrapping paper the nails were delivered in had adhered to some of their heads and insulated the nails from the copper. Upon witnessing the results, the Admiralty dictated that iron nails should not be allowed to be used with copper in a salt water environment. This action reflects an early step in combating corrosion spawned by joining two dissimilar metals in an electrolyte or salt water and this kind of corrosion is now known as galvanic corrosion (Tretheway & Chamberlain, 1988). Corrosion knowledge has advanced greatly over the past three hundred years and the more proactive the sailors become, limiting corrosion will be more effective.

During the hands-on training, the sailors will be gaining a great deal of knowledge through hands-on learning. According to Martin (1985), "Technology education has continued to focus on hands-on activities and modified them, helping students to become technologically literate by developing problem solving adaptation skills and a positive attitude toward technology" (p. 4). Before the crews begin any process of corrosion control a solid understanding of what corrosion actually is will be necessary. The more knowledge and practical skills the sailors have the more valuable they will be to the U. S. Navy and future employees. Dewey (1963) felt that "any mode of skill which is achieved with deepening of knowledge and perfecting of judgment is readily put to use in new situations and is under personal control" (p. 259).

In order for sailors to understand that corrosion control is actually doing any good for their ship they need to be armed with a basic concept of what corrosion is. They will need to know that it is a chemical reaction and is often considered an interdisciplinary subject combining elements from physics, chemistry, metallurgy, electronics, and engineering. It has to be understood that it is a natural process governed by energy changes. The study of energy changes is thermodynamics, employing many definitions, variable quantities, and equations. The First Law of Thermodynamics is: Energy can neither be created nor destroyed, and since energy plays an important part in corrosion, this law is very important to corrosion control. The Second Law of Thermodynamics is: All spontaneous changes occur with a release of free energy from the system to the surroundings at constant temperature and pressure. Corrosion is a spontaneous process therefore releasing free energy. There are many kinds of energy, but the sailors should only need to know that all substances have internal energy – the energy stored within the chemical bonds of a substance. Only a small portion of this energy is actually available and that is called free energy (Tretheway & Chamberlain, 1988).

An explanation of the Transition State Theory will give the sailors a clearer understanding of the corrosion process and aid in explaining the rates of corrosion reactions. Consider the equation below:

$$A + B \rightarrow C + D$$

In the equation species A and B are the reactants, while C and D are the products. The equation is a shorthand meaning, species A and B interact together in such a way to form two other species, C and D. Before C and D can be formed, species A and B need to do more than just connect; they need to join together, creating an intermediate species, AB. The creation of AB is very quick and requires significant energy and the proper orientation. AB is called the 'Transition State' which leads to the creation of products C + D (Tretheway & Chamberlain, 1988).

The factors affecting corrosion in an ocean environment will be another necessary aspect added to knowledge gained by the sailors. They need to know that corrosion of metal is very similar to that of a car battery. One of metals will act as a cathode; the other will be the anode and the deposited saltwater will act as an electrolyte. The cathode is more positive than the anode and the electrolyte is a solution that conducts electricity. Through the electrolyte there will be a passage of electrons from one to the other. Within this corrosion cell or circuit, one metal will release electrons undergoing an oxidation reaction while the other is experiencing a reduction reaction by consuming electrons. As the oxidizing metal weakens with the loss of electrons a new component is produced, better known as a corrosion product. These products or oxides may be in the form of white aluminum oxide or rust (Tretheway & Chamberlain, 1988). It is important for the sailor to understand that rust is not the start of corrosion, but an indication that corrosion has been occurring for some time.

Sailors need to be aware that a ship can be exposed to many conditions that can bring about corrosion. In a marine environment atmosphere winds carry small particles of wind and the amount of corrosion will be affected by rainfall, wind velocity, temperature dust, solar radiation, and pollution. Awareness that the splash zone of a ship is the most aggressive zone since maintaining protective coatings are very difficult and Tidal activity poses a threat due to oil coating from polluted harbor water are very important. It is important to note that when a ship transits shallow waters, its hull is closer to sediment and oxygen while in deeper waters, water temperatures and amounts of oxygen vary drastically (Schumacher, 1979) .

TYPES OF CORROSION

To further arm the students with knowledge, they will need to know some of the different types of corrosion, especially the kind found aboard ship. Seawater acts as an electrolyte, when two different metals are joined together severe galvanic corrosion occurs. Similar to a car battery, one metal acts like an anode at one potential and the other is very much like a cathode. Since the salt water and its impurities are the electrolyte, current begins to flow, oxidation forms, and corrosion occurs. The greater the potential differences are between the two metals, the more the corrosion is accelerated (Schumacher, 1979).

Another form of corrosion is atmospheric, which is very much like galvanic with the exception that humidity and air contaminants become the electrolyte. As the moisture saturates the area between two dissimilar metals, current flows once again and corrosion occurs (Tretheway & Chamberlain, 1988).

Some other forms of corrosion are: crevice attack which occurs to metals immersed in sea water that require oxygen to repair its oxide film; pitting, which are considered localized attacks brought on by discrete salt particles or contaminants and impingement which happens to metals that are susceptible to the current flow of the ocean. Corrosion can also be brought on by temperature shifts, high current or stray-current, impurities introduced into liquid metals, and even microbiological organisms (Cramer & Covino, 2003).

There are many forms of corrosion. Metallic corrosion often leaves plenty of visual signs indicating its progress. In most cases the visual corrosion product is oxidation, better known as rust or a patina. There are cases where corrosion is not obvious. One place that is of concern is where an antenna base mounts to a ship’s superstructure.

THE NEED FOR INFORMED TRAINING

Antennas come in all shapes and sizes. They work in many frequency ranges and have different power requirements. Their functions may be receive, transmit, or both. On Navy ships the technician may be told to perform maintenance on a particular antenna system but does not fully understand the need to be aware of the ramifications of cutting corners. Knowledge of their ship's basic construction is extremely important. Some ships are made completely of aluminum or steel or a mixture of both. Some antennas are made of aluminum and some of fiberglass. When a technician is sent to perform maintenance they are given a set of instructions, telling them to look for corrosion. When they get out on the platform and finally work the mounting bolts free, they may or may not notice a white dusty substance underneath and think nothing of it. The technician may also bring mounting hardware to replace the old bolts and not realize that they may be introducing hardware that will rust in place.

The Navy technicians know that corrosion is bad, but recognition of corrosion is not always obvious. A rusty bolt at the base of antenna is obvious, but the oxidation under the base of an antenna is not. This oxidation is not conductive, causing partial isolation between the antenna and its ground plane. A ground plane is the structure an antenna is mounted on and, theoretically it is a reflection of that antenna. The better the ground, the better the antenna will radiate (Stutzman & Thiele, 1981).

THE NAVY STUDENT

Gagne, Briggs, and Wager (1992) identified eight different types of knowledge: signal learning, stimulus response, motor training, verbal association, discriminative learning, concept learning, verbal association, discrimination learning, concept learning, rule learning, and problem solving. According to Merriam, Caffarella, and Baumgartner (2007), Gagne, Briggs and Wager had the most developed method of connecting instruction to acquiring and processing of knowledge.

The Combat Systems sailor will need to get into the practice of responding before the catastrophic effects of corrosion takes hold and initiate the general response that corrosion may be one of the causes of equipment problems. The trained sailor will be able to make a more precise response by visually inspecting the site, making resistance checks, or separating metal-to-metal joints in order to verify the presence of corrosion. Once the sailor has concluded corrosion has occurred, they will be comfortable identifying the type of corrosion detected and begin the necessary corrective treatments. The sailor will be a subject matter expert and will be able to authoritatively report the problem to their chain of command. The shipboard subject matter expert will recognize that since the same types of corrosion are experienced at the waterline to the top of the mast, they will know that the same corrective procedure will be used. The sailors will learn the rules and know where to find them if they forget them and they will be effective troubleshooter and problem solvers.

In order to evaluate the success of learning, questionnaires will be issued at the end of the initial meeting with the ship. The sailors involved will be asked their honest opinion on the training and if their perception of corrosion had changed and to what extent. They will also be asked if the use of calibrated ohm meters helped in comprehending the importance of what was involved. They will also be asked for suggestions on how to best combat corrosion and whether they will put into practice what they have learned and are willing to share this knowledge with untrained sailors.

SUMMARY

The resources included in this chapter provided financial reasons, a basic corrosion theory, an understanding for the need, and a new approach to improve behaviors of technicians. Whether one wants to accept the estimated initial cost of $20 billion dollars or the estimated overall cost of $435 billion to the military, the price tag is extremely high. It was noted that in addition to direct financial costs, indirect costs such as lost productivity, delays, litigation, taxes, and overhead costs place a huge financial strain on the economy (GAO, 2004).

The FHWA (2004) recommended a preventive strategy including cost awareness plans and changing paradigms of defenselessness against corrosion. Recommendations to adopt new policies and rules were made. They were very strong in advocating corrosion prevention training and education. Improved research and development, design practices, advanced life predictions, and performance assessment methods need to be introduced.

A difference between rust, a product of corrosion, and the actual corrosion has been made. It has also been pointed out that the technicians need to be aware the corrosion is not always visible but may negatively impact the operation of important

Combat Systems equipment. The environment a ship operates in greatly determines the amount of corrosion experienced.

The U. S. Navy is moving forward to educate and teach sailors onboard their own ships. By arming sailors with information about the causes and effects of corrosion they will have a better understand of why they are doing the preservation and will be motivated to correct deficiencies. Chapter III describes the methods and procedures used in this research.

CHAPTER III

METHODS AND PROCEDURES

The purpose of this chapter is to outline the methods and procedures used to conduct this study. This experimental research was a quasi-experimental study. This chapter includes the population of this study, research variables, instrument design, methods of data collection, statistical analysis, and summary.

POPULATION

The population being trained will be shipboard technicians familiar with antenna maintenance and basic test equipment operation. The sailors receiving Combat Systems corrosion training will have knowledge of electronics, electronic theory, and understand test equipment fundamentals. These technicians will be familiar with basic technical procedures and relate safety procedures according to Navy specifications (NAVSEA PUB 4790.8C, 2009). The technician will be responsible for the system or a system closely relating to the system under test. There were 63 sailors involved with the training.

RESEARCH VARIABLES

This study investigated how the independent variables of theoretical training in corrosion and impedance testing before and after corrosion preventive measures helped sailors in understanding corrosion control processes. Hands-on training was held on two U.S. Navy ships and carried out in a topside environment. The duration of training for each ship lasted for a period of approximately one month. The training day went from 8:00 AM to 2:00 PM, Monday through Friday, with a review of training held every Friday at 3:00 PM. The study was from 08 May to 09 July 2010.

INSTRUMENT DESIGN

A calibrated Fluke® 170 Series Multi-meter was used to read the resistance during this research. Questions were generated regarding the affects corrosion has on Combat Systems Equipment. The questions also queried the level of comprehension the sailors felt they gained after the training and taking measurements. Resistance measurements were taken at four bases of UHF antennas, two HF antenna bases, and one vertical ladder where the four corners are bolted to ladder stanchions on each ship. Since corrosion is inconsistently influenced by the surrounding environment, resistance between corroded metal-to-metal joints will not be the same. For this reason the multi-meter will be used to document difference between the resistances measured before and after the sailors have completed each corrosion control process.

METHODS OF DATA COLLECTION

The researcher held an introductory lesson prior to beginning hands-on corrosion control training. The first step in the process was for the technicians to utilize the multi-meter to acquire baseline impedance levels. The corrosion control procedure ensued until completion and another impedance measurement was taken at the end. The sailors were then asked to compare the two measurements. After the corrosion control process was finished, the impedance reading was lower, easing current flow. Before departing the ship, the technicians were given a questionnaire, asking if they felt that they understood corrosion better and comprehended the need to be more proactive in preventing the problem. See Appendix A for the sample questionnaire.

STATISTICAL ANALYSIS

After all data were tabulated and analyzed on the basis of the results of the surveys. Each survey question means was computed.

SUMMARY

This chapter provided information on the methods and procedures used for data gathering needed to perform the research. The population was enlisted sailors trained in electronics and undergoing Combat System corrosion control training. The instrument used was a questionnaire that sailors would voluntarily complete and return to a drop box located in the Combat Systems Office. The students measured resistance levels with a Fluke® 170 Series Multi-meter before and after performing corrosion control processes and documented the changes. These changes were used to emphasize the damaging effects of corrosion and the effectiveness of practicing sound corrosion control measures. Chapter IV describes the findings and analyzes the data collected.

CHAPTER IV

FINDINGS

The purpose of this study was to determine whether taking resistance measurements before and after performing corrosion control procedures on two U. S. Navy ships would help shipboard technicians better comprehend the results of their corrective efforts in the area of corrosion control. The problem of this study was to evaluate the success of combat systems topside preservation training using a cost efficient method to self-assess the efficiency of shipboard corrosion control procedures. This chapter contains an overview of information gathered, as well as a table which graphically represents the information collected. A summary of findings that resulted from the collected data will also be included in this chapter.

RESEARCH PARTICIPANTS

The subjects of this study were 63 U. S. Navy enlisted sailors. Each sailor was a technician trained in electronics and familiar with measuring resistance using a multi-meter. These sailors were members of their respective ship's Combat Systems Department and undergoing corrosion control training. Two U. S. Navy ships were the test platforms and the data were gathered during the spring and summer of 2010.

TECHNICIAN SURVEY RESPONSE RATE

Of the 63 surveys received, all were from E-1 through E-6 combat systems technicians with 2 to 15 years experience.

SURVEY RESULTS

The five survey questions were designed to answer the hypothesis of this study. A five-point Likert Scale was utilized to rate the responses of contributors. Technicians taking part in the survey responded to each question by selecting “Strongly Agree” (SA), “Agree” (A), “Undecided” (U), “Disagree” (D), or “Strongly Disagree” (SD) as selected scaled responses. Mean scoring was employed describing the technicians’ assessment of the value of each question posed.

Question 1 asked if integrating resistance measurements with on-the-job training helped the students in understanding the need to practice good corrosion control methods. Of the 63 sailors who completed the questionnaire, 26 selected “Strongly Agree”, 25 picked “Agree”, and 12 chose “Undecided” as their responses to the statement. The calculated mean score for this statement was 4.2 on a 5.0 scale. Based on the resultant mean score, the sailors agree that the integration resistance measuring with corrosion control training aided in the need to follow sound corrosion control practices.

Question 2 asked whether the integration of taking resistance measurements with corrosion theory training helped the students in better understanding the need to practice sounds corrosion control methods. Of the 63 sailors who completed the questionnaire, 27 selected “Strongly Agree”, 28 percent picked “Agree”, 7 chose “Undecided”, and 1 opted for “Disagree” (D) as their responses to the statement. The calculated mean score for this statement was 4.3 on a 5.0 scale. Based on the resultant mean score, the sailors agree that the integration resistance measuring with corrosion theory training helped in the need to practice sound corrosion control methods.

Question 3 asked if comparing before and after resistance readings provided the students with a better idea of the damaging effects of corrosion. Of the 63 sailors who completed the questionnaire, 20 selected “Strongly Agree”, 25 picked “Agree”, and 18 chose “Undecided” as their responses to the statement. The calculated mean score for this statement was 4.0 on a 5.0 scale. Based on the resultant mean score, the sailors agree that comparing before and after resistance readings afforded them with a better impression of the damaging effects of corrosion.

Question 4 asked if comparing before and after resistance readings provided the students with a better understanding of the positive effects of following sound corrosion corrective actions. Of the 63 sailors who completed the questionnaire, 23 selected “Strongly Agree”, 24 picked “Agree”, and 16 chose “Undecided” as their responses to the statement. The calculated mean score for this statement was 4.1 on a 5.0 scale. Based on the resultant mean score, the sailors agree that comparing before and after resistance readings provided them with a better appreciation for the positive effects that result from adhering to sound corrosion control corrective actions.

Question 5 asked if integrating resistance measurements and corrosion theory training is a valuable addition to Combat Systems corrosion control training. Of the 63 sailors who completed the questionnaire, 26 selected “Strongly Agree”, 35 picked “Agree”, 1 chose “Undecided”, and 1 opted for “Disagree” (D) as their responses to the statement. The calculated mean score for this statement was 4.4 on a 5.0 scale. Based on the resultant mean score, the sailors agree that the integration of resistance measuring with corrosion theory education would be an asset to Combat Systems corrosion control training. Table 4 is a graphical representation of data collected and calculated in support of this research. Under columns SA, A, U, D, and SD, the top numbers are the actual number of questionnaire responses corresponding to the scale and those inside the parentheses are the related percentages.

Table 4

Frequency of sailors' responses to survey questions and means score.

Survey Question	SA	A	U	D	SD	Mean
Q-1 Integrating resistance measurements with on-the-job helped me understand the need to practice good corrosion control methods.	26 (41.27)	25 (39.68)	12 (19.05)			4.2
Q-2 Integrating resistance measurements with corrosion theory training helped me understand the need to practice good corrosion control methods.	27 (42.68)	28 (44.44)	7 (11.11)	1 (1.59)		4.3
Q-3 Comparing before and after resistance readings provided me with a better idea of the damaging effects of corrosion.	20 (31.75)	25 (39.68)	18 (28.57)			4.0
Q-4 Comparing before and after resistance readings provided me with a better understanding of the positive effects of following sound corrosion corrective actions.	23 (36.51)	24 (38.1)	16 (25.4)			4.1
Q-5 Integrating resistance measurements and corrosion theory training is a valuable addition to Combat Systems corrosion control training.	26 (41.27)	35 (55.56)	1 (1.59)	1 (1.59)		4.4

SUMMARY

This chapter included data collected from surveys completed by sailors who underwent Combat Systems corrosion control training and integrated the activity of taking before and after resistance measurements as a self-assessment. Designed to answer the study's hypothesis, the five statements constituting the survey were conceived to appraise the level of comprehension shipboard technicians experience after the introduction of before and after resistance measurements into Combat Systems corrosion control training. As a graphical depiction of the accumulated data a table using the Likert Scale was employed to rate survey responses.

For all questions, the majority of responses were either in agreement or strong agreement with the statements. Questions 3 and 4 had higher undecided responses than the rest. For Questions 2 and 5 there was one disagreement for each statement. In Chapter V, the results of this chapter will be interpreted and conclusions of the study will be made. Additionally, recommendations for further and similar cognitive studies in Combat Systems corrosion control training will be suggested.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter provides a summary of this research. Additionally, this chapter presents conclusions for the study and offers recommendations for future studies on the topic.

SUMMARY

The problem of this study was to evaluate the success of combat systems topside preservation training using a cost effective method to self-assess the efficiency of shipboard corrosion control procedures. As a guide for the research, the hypothesis stated was: On Navy ships calibrated ohm measurements will better quantify the effectiveness of present shipboard topside corrosion control practices, was used.

Two significances behind this study were the high cost of corrosion related maintenance for both the U.S. Navy's Atlantic and Pacific Fleets and the extended amount of time a ship will need to remain in the shipyard correcting those problems. U. S. Navy ships regularly operate in highly corrosive environments and are often deployed for extended amounts of time. At the end of their deployments ships enter into shipyard periods for maintenance. During this time, much of the maintenance funding and hours are allocated to correcting corrosion related problems. Serious corrosion problems can be so extensive that a ship may end up having its yard period extended beyond their shipyard availability dates forcing another ship to take its place and meet its commitment.

Another supporting significance behind this study is personnel and equipment safety. Corroded mating surfaces for ladders and climber safety rails pose a fall-hazard for those working on the mast. If the faying surface between two metal components becomes corroded the mounting hardware chances deterioration and presents a possibility of objects falling. Corroding antenna bases and equipment platforms may cause equipment and personnel casualties. If corrosion intrudes between the mounting surfaces of external equipment and the ship's hull increased resistance between the two surfaces may ensue. This change in resistance may affect sufficient ground potential between the ship's structure and the attached equipment that a shock hazard may present itself.

Having a more informed and better trained sailor will reduce maintenance costs and safety issues relating to corrosion. The more knowledge the technician has the longer the equipment will remain online and the probability of corrosion related problems being correctly repaired will improve. Armed with this knowledge the technician will be more cognizant of the fact that properly performed corrosion control processes extend the life of areas being preserved by reducing times between treatments and makes for a safer environment for the ship. The additional understanding behind corrosion may interest a sailor enough to go further into the science of corrosion and pursue a degree in the field.

The action of recording before and after resistance measurements is a supporting behavior of the overall cognition of Combat Systems corrosion control training. By self-evaluating the differences between measurements, students receive immediate feedback about from the process. Comparing resistance readings will inform the student that the same potential between surfaces had been accomplished by their efforts. The sailors will learn while doing. While they are being lectured, these shipboard technicians will be able to closely visualize the problems, take a resistance check if possible, identify the type of corrosion, and learn to apply the proper corrective and preventive measures.

One of the limitations to this study was that both of the ships used in the research were the same class of ship. Even though each ship was the same class, they experienced different corrosion problems which limited the kind of training given. Weather and time aloft limited the location and amount of time that could be dedicated to the kind of training. Cost limitations did not permit the use of radiating elements to provide more in depth results. Access to locations onboard the ships were not always available. Ships were replacing warn deck coatings and non-skid surfaces. This process lasted two weeks, restricting access to different parts of the ship. The drills held by the ships limited movement and took sailors away from training. The amount of anti-seize applied between metal surfaces was not always uniform and affected the impedance measurements over a period of time. The sealant used was not always given ample time to dry before applying primer and paint and might peel away at a later date, exposing repaired surface. The paint used was not always applied at the optimum temperature and may not last as long as it would if applied at the proper temperature. The Corrosion Resistant Steel (CRES) replacement hardware may not have been manufactured properly resulting in poor corrosion resistant properties. Treatable corrosion products were limited oxides created from steel, aluminum, and copper. The list of problems presented by the combat systems officer or electronic material officer may not have included all corrosion problems.

The population involved in this research was shipboard technicians familiar with antenna maintenance and possessed a basic knowledge of test equipment operation. These sailors were technicians trained in electronic theory, versed in shipboard safety procedures, and responsible for the systems involved in the corrosion control process.

At the conclusion of the training, questionnaires were delivered to Combat Systems Department and a drop box was provided for completed forms. The surveys comprised of five statements developed to assess student opinion of before and after resistance measurements taken during Combat Systems corrosion control training and how much of an essential part of their training these measurements were. The researcher used the Likert rating scale in order to rate sailor responses to each question. The ratings were “Strongly Agree” (SA), “Agree” (A), “Undecided” (U), “Disagree” (D) or “Strongly Disagree” (SD). Of the 94 sailors who participated in the training, 63 turned in completed questionnaires for 67 percent response rate.

CONCLUSIONS

The problem of this study was to evaluate the success of combat systems topside preservation training using a cost effective method to self-assess the efficiency of shipboard corrosion control procedures. The hypothesis: On Navy ships calibrated ohm measurements will better quantify the effectiveness of present shipboard topside corrosion control practices, was used as a research guide. In order to support the problem statement and hypothesis of this study, the researcher distributed a five statement survey. The results from the 63 completed were then reduced to nominal levels and combined into two categories of “accept” and “reject.” The results were as follows: statement one earned 51 in the “accept” category, 12 were marked as undecided and discarded, and zero were placed in the “reject” category; statement two earned 55 in the “accept” category, seven were marked as undecided and discarded, and one was placed in the “reject” category; statement three earned 45 in the “accept” category, 18 were marked as undecided and discarded, and zero were placed in the “reject” category; statement four earned 47 in the "accept" category, 16 were marked as undecided and discarded, and zero was placed in the "reject" category, and statement five earned 61 in the "accept" category, one was marked as undecided and discarded, and one was placed in the "reject" category.

Overall, the sailors were in agreement with all of the statements. Based on the data collected, the researcher is justified in accepting the hypothesis that on Navy ships calibrated ohm measurements will better quantify the effectiveness of present shipboard topside corrosion control practices.

RECOMMENDATIONS

Based on the findings of this study it is recommended that comparing before and after resistance measurements should be implemented into the Combat Systems corrosion control training curriculum. These measurements provide the sailors with a better understanding of the negative effects of corrosion and an appreciation of their efforts to correct corrosion problems. Additionally, this procedure should be adopted as a part of Combat Systems corrosion control training since it is a method of self-assessing the technicians' work, and it is supportive of The Department of Defense focus on corrosion training (GAO, 2004).

An additional study may include the comparison of signal properties of combat system equipment transmissions that are measured before and after systems undergo corrosion control corrective procedures. This would be another way for students to assess before and after measurements and perform self-evaluation of their work.

Using before and after resistance measurements can be used in private industry. Introducing these procedures into corrosion control training in manufacturing settings should have similar positive results that are experienced in the U. S. Navy Combat Systems training environment. The negative effects of corrosion are universal (FHWA, 2001). Comparing before and after resistance measurements should be an important part of any curriculum designed to train corrosion control of metals.

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APPENDIX – STUDENT QUESTIONNAIRE

Questionnaire:

Instructions: This questionnaire is voluntary. In order to protect individual privacy, do not put your name, ship's name, date, rating or rank anywhere on this questionnaire. Below are statements dealing with the value of using before and after resistance measurements during shipboard corrosion control training. Please rate how much you agree or disagree with the following statements by marking the appropriate box. If you strongly agree, mark SA; if you agree, mark A; if you are undecided, mark U; if you disagree, mark D, and if you strongly disagree, mark SD. Upon completion, turn this questionnaire into the Combat Systems Office.

	SA	A	U	D	SD
1.) Integrating resistance measurements with on-the-job helped me understand the need to practice good corrosion control methods.	○	○	○	○	○
	SA	A	U	D	SD
2.) Integrating resistance measurements with corrosion theory training helped me understand the need to practice good corrosion control methods.	○	○	○	○	○
	SA	A	U	D	SD
3.) Comparing before and after resistance readings provided me with a better idea of the damaging effects of corrosion.	○	○	○	○	○
	SA	A	U	D	SD
4.) Comparing before and after resistance readings provided me with a better understanding of the positive effects of following sound corrosion corrective actions.	○	○	○	○	○
	SA	A	U	D	SD
5.) Integrating resistance measurements and corrosion theory training is a valuable addition to Combat Systems corrosion control training.	○	○	○	○	○